Modeling Team Performance in the Air Defense Warfare Domain[1]

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Decision Support Systems and Models for Intelligent Mission Management

Background

•Multi-mission, multi-tasking, optimally manned CICs will require greater reliance on automation.

•Operators will require resource management tools and planning aids to meet mission requirements - these ***must*** reduce workload in the planning and execution process

GOALS

1. **Model** individual operator and team performance.
2. Simulate and quantify the effects of increasing and decreasing team size providing a model of manning and automation requirements.
3. Test the nature of task allocation and dynamic task reallocation schemes among team members and autonomous agents.
4. Develop methods to dynamically predict team performance.
5. Develop displays to depict actual team performance dynamically to team leaders and methods to recommend changes towards optimization.
6. Discover behavioral results of team performance awareness with regard to team self-monitoring and correction.

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Purpose of Modeling

- Predict impact of design on human performance - before system is built.
- Compare alternative designs.
- Compare alternative job structures, positions, team definitions.
- Predict and compare performance results for design reference missions.
- Reduce design risk.
- Identify design changes and corrections before costly mistakes made.

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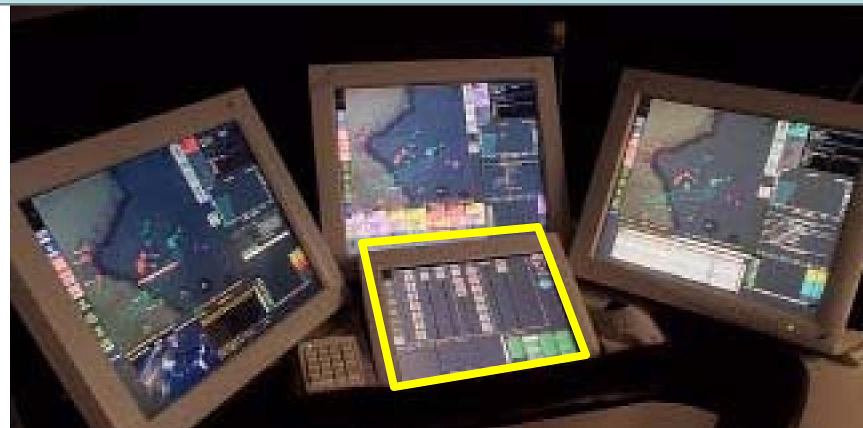
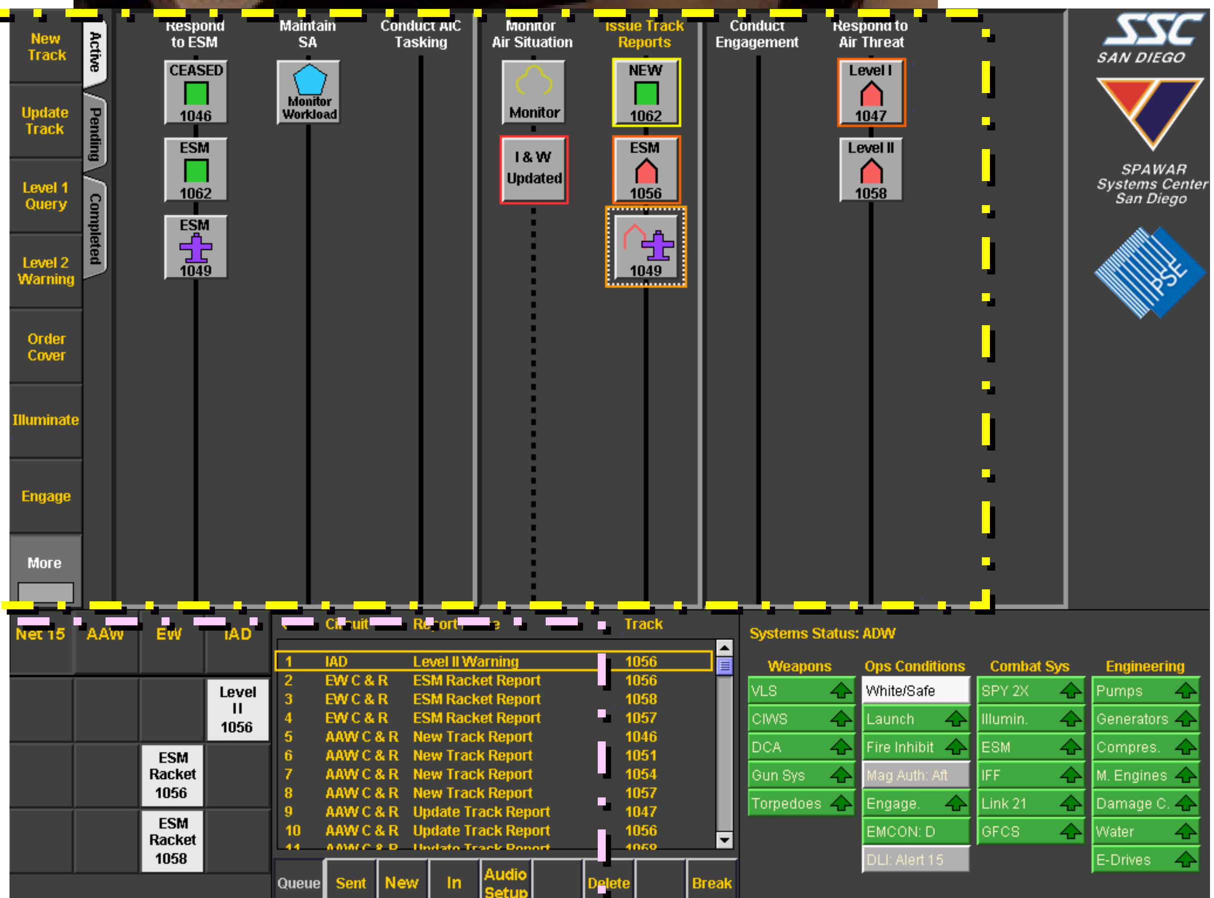
Task Manager & Status Display



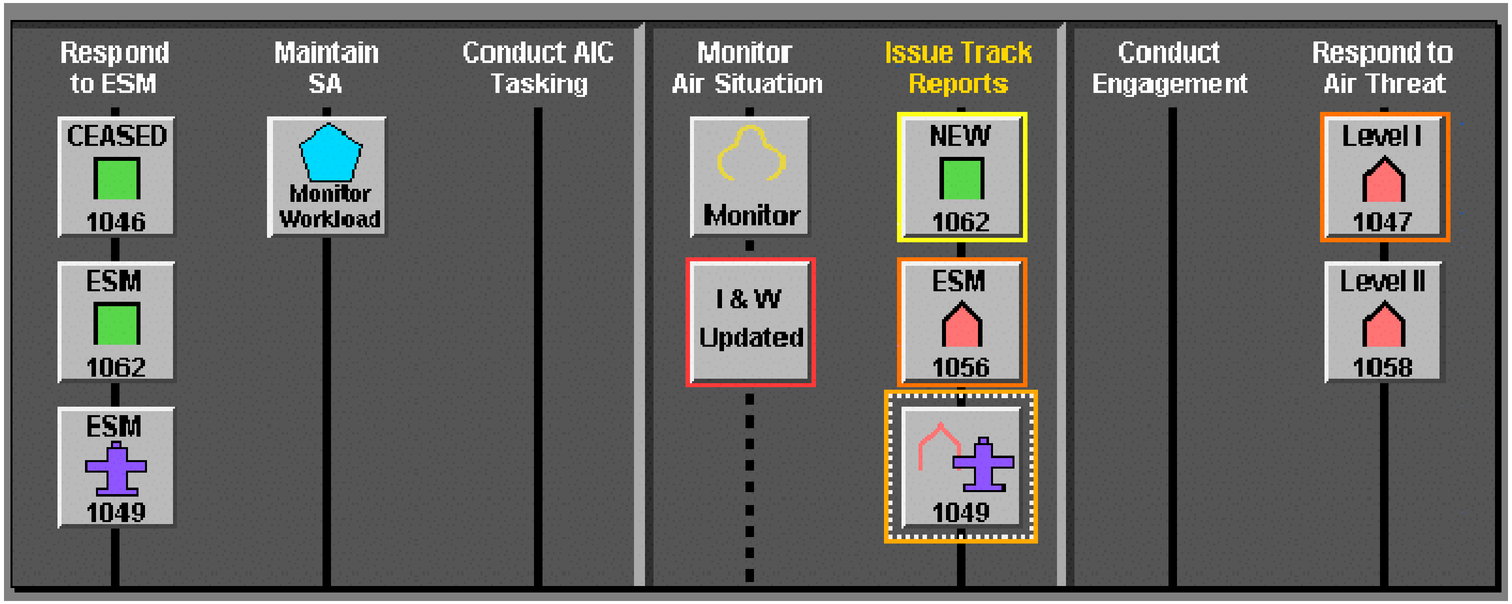
Task Manager Task Queue



Communications

Systems Status

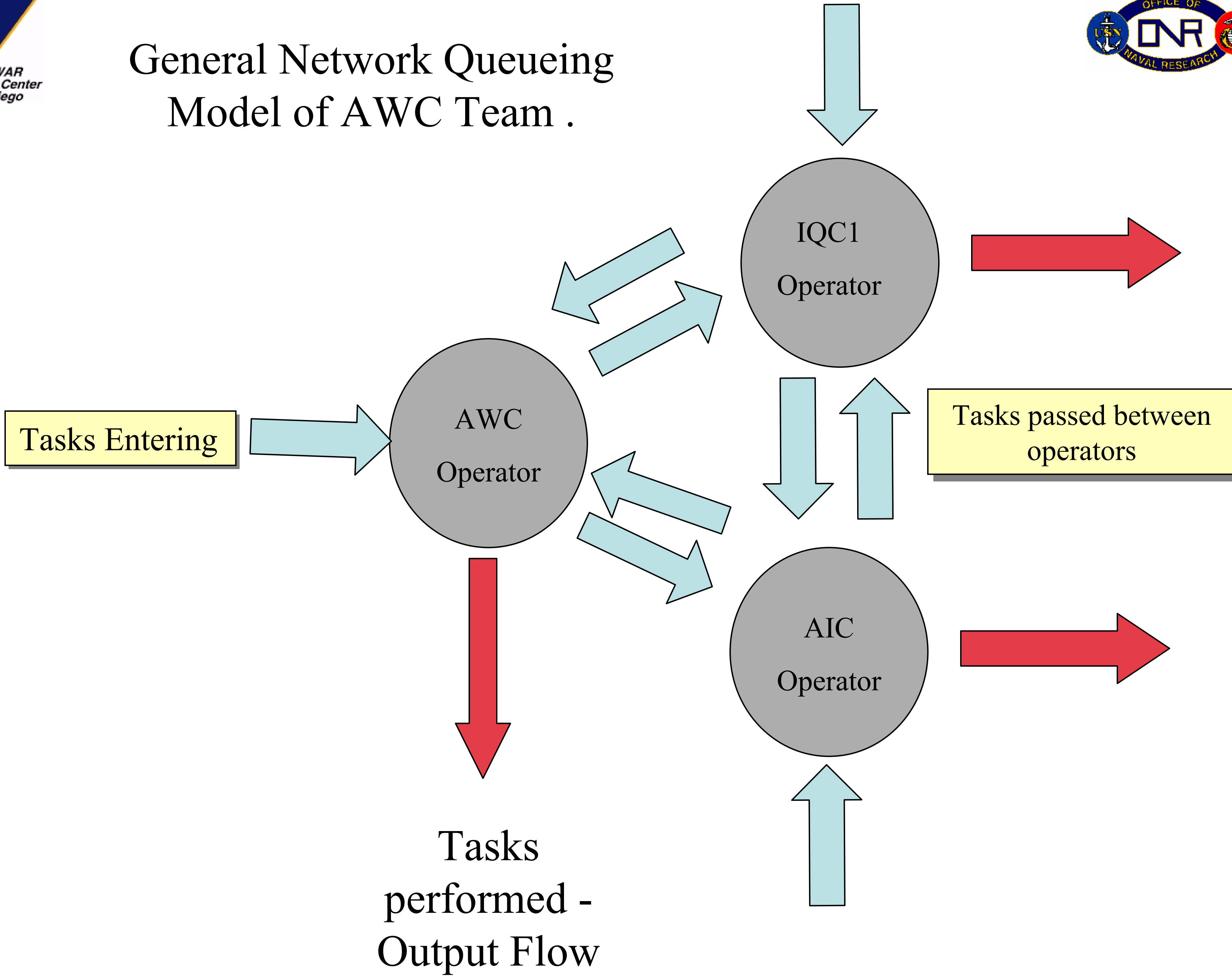
Air Defense Battle Group Task Monitoring



Representation of work in terms of tasks servers as a trace - enables designers to track workload and flow of tasks among team members.

Posting of Task analogous to customers arriving at a queue for service: Model Teams with Queueing Theory and Queueing Networks.

General Network Queueing Model of AWC Team .



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Components of Queueing Model

A) The input or arrival process is usually modeled as a stochastic process, such as a Poisson process. In our case, the customers are tasks arriving on the TM display.

B) The service mechanism refers to the number of "servers" and the lengths of time the customers hold servers. This is usually modeled with a negative exponential, and in our case this is the number of operators and the distributions of reaction times it takes operators to perform various tasks.

C) The queueing policy entails the method by which the system selects customers: first-come-first-served (FCFS), last-come-first-served (LCFS), by priority, or at random.

Queueing Models

- Different Team Task Allocation Schemes can be represented by Network Queueing Models.
- Queueing Models make Quantitative Predictions of "Throughput" different for each team:

  1) Average Time a Task Stays in the System (from "birth to death").

  2) Average Number of Tasks in the System.

  3) Average Number of Tasks for each operator.

  4) The distribution of system states - the percentage of time there are n outstanding tasks to perform.

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Air Def. Warfare MMWS Experiments

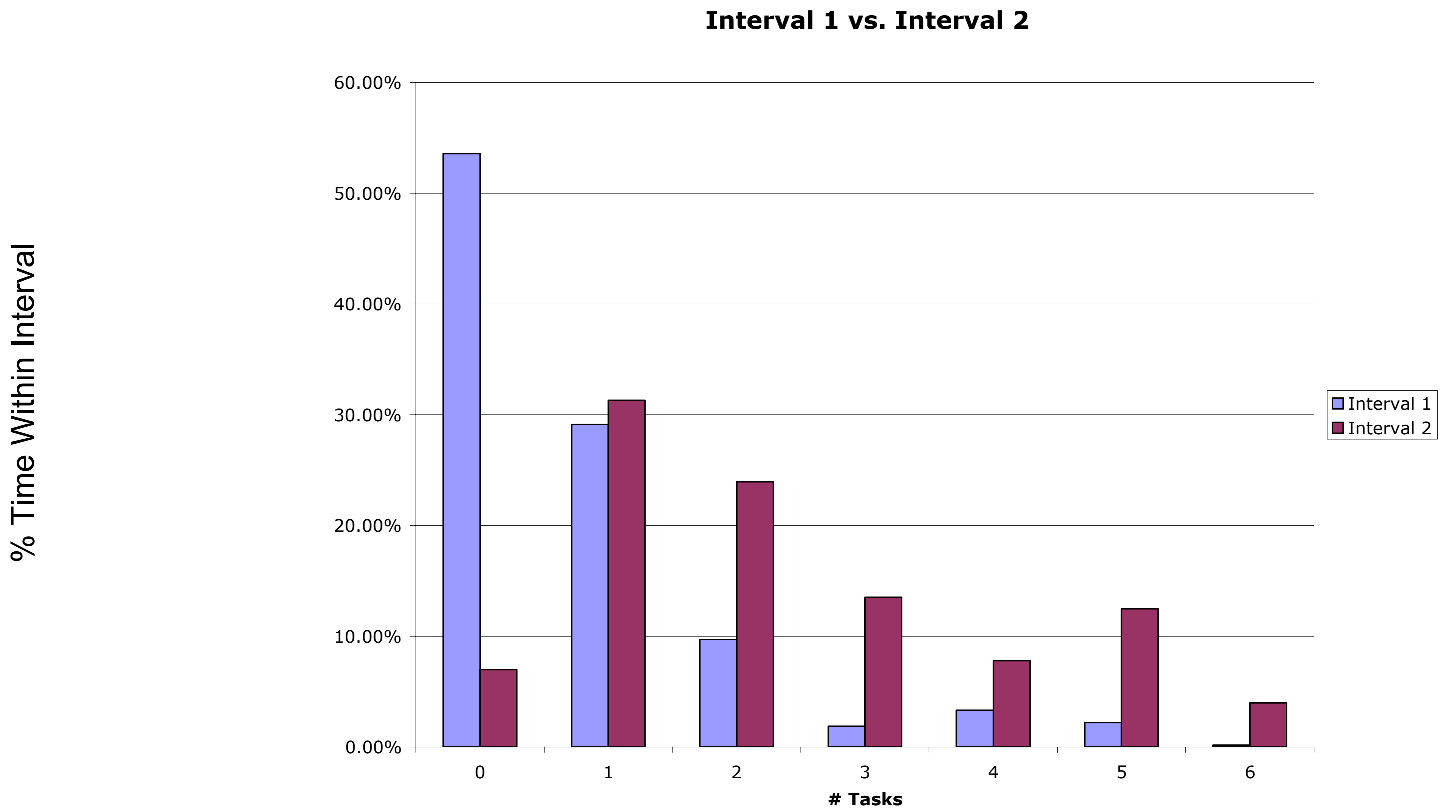
- Four 5-member ADW teams were tested on a 2 hour Scenario - Sea of Japan (SOJ).
- Tactical Action Officer, Air Warfare Coordinator, Information Quality Control (2), Air Intercept Controller.
- Operators were assigned Primary and Secondary Tasks.
- All system recommended tasks were presented on a Task Manager (TM) Display.
- All Teams "self-organized" - were "free" to allocate tasks amongst themselves - not told how or when to reallocate.
- Only support for allocation was visual - listing of tasks on the TM display.

The results provide a basis for building team models.

Results show a contrast between team performance outcomes.

Team 1 Air War Coordinator "States"

% of Time spent by number of tasks to perform.

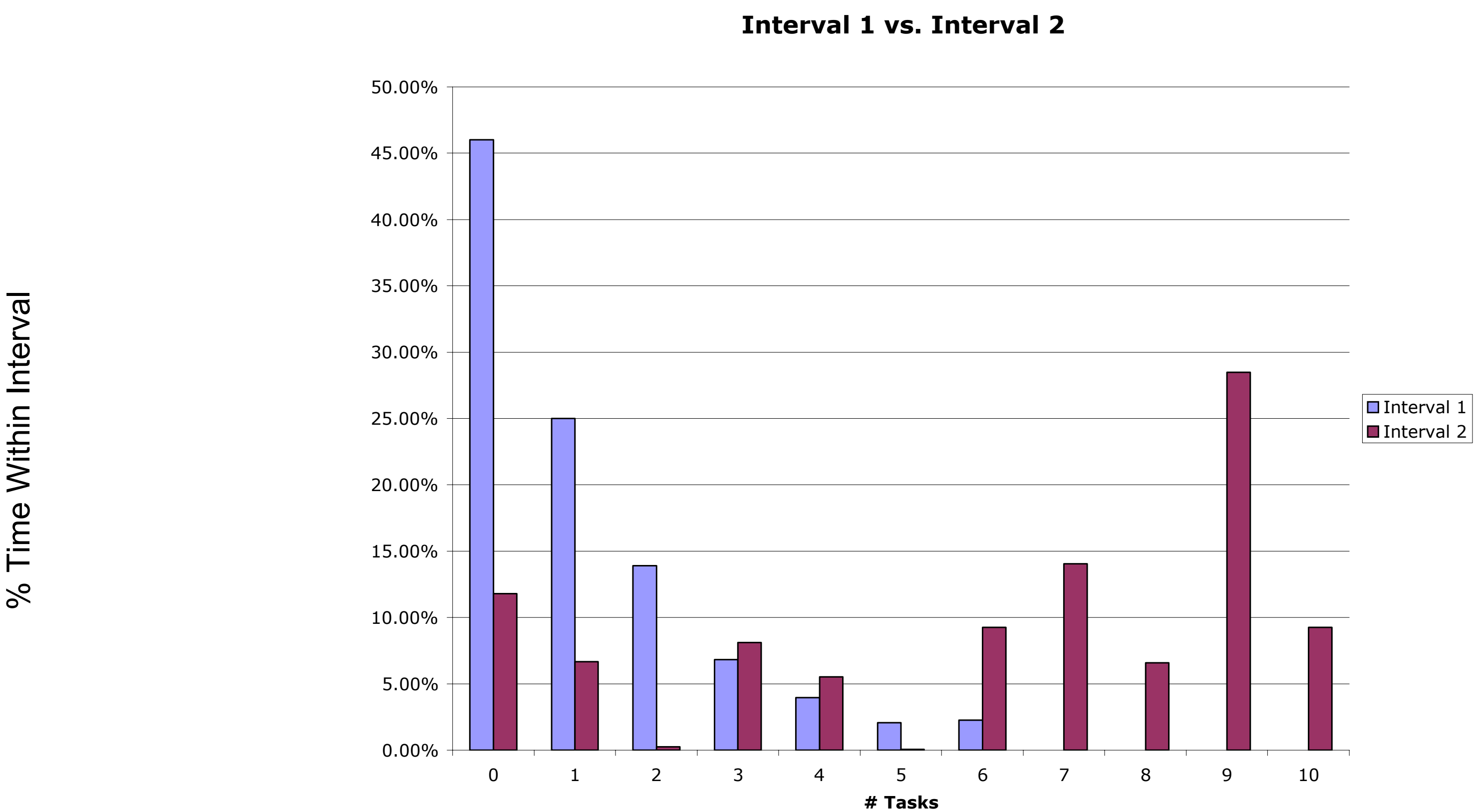


Scenario Interval 1 (Low workload) Scenario Interval 2 (High workload).

Higher workload interval marks a shift in states where AWC begins to fall behind completing tasks.

Team 2 Air War Coordinator “States”

% of Time spent by number of tasks to perform.



Scenario Interval 1 (Low workload) Scenario Interval 2 (High workload).

Higher workload interval marks a shift in states where AWC begins to fall behind completing tasks.

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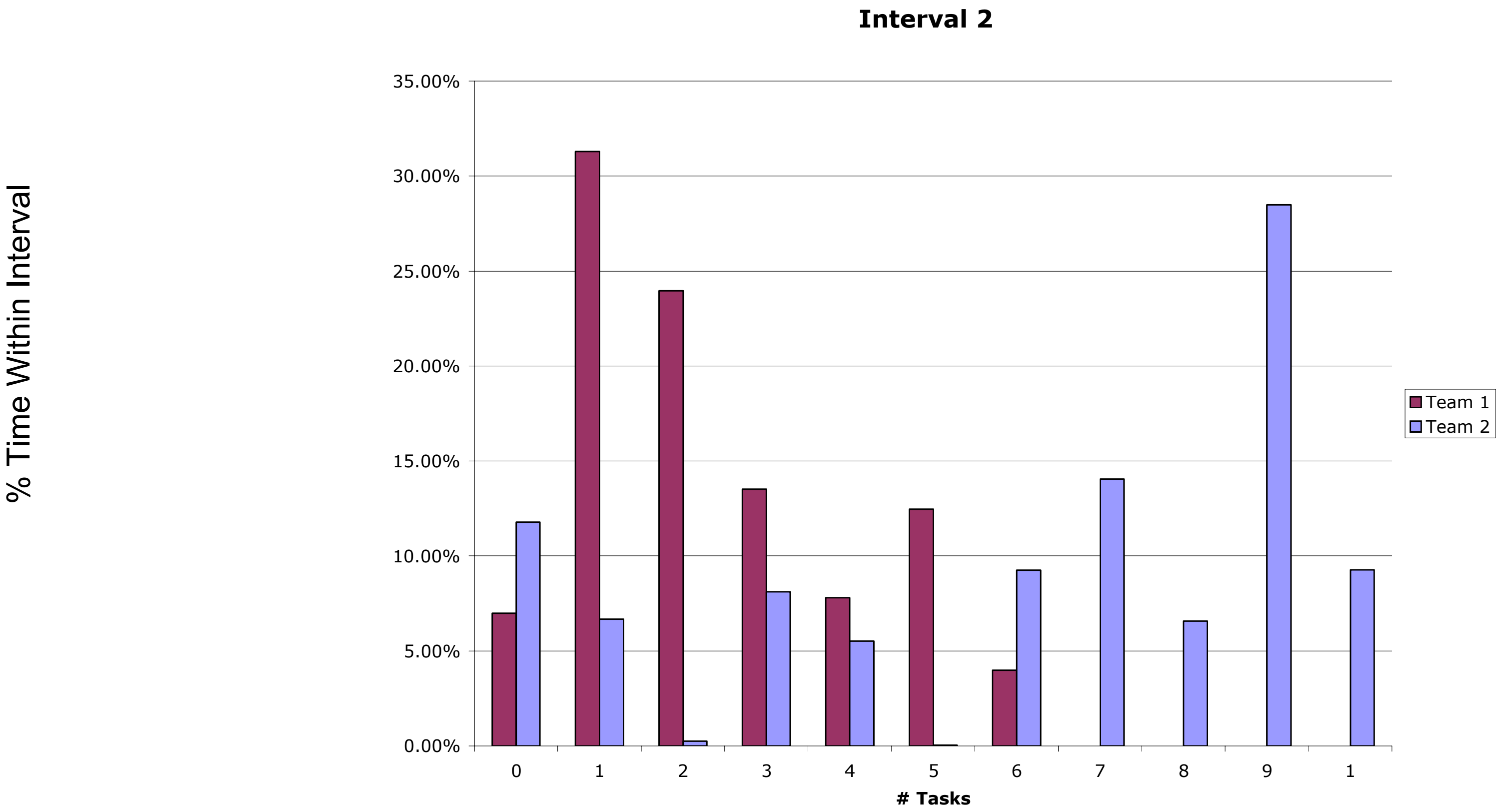
Team 1 and 2 AWC States Comparison During Period of High workload

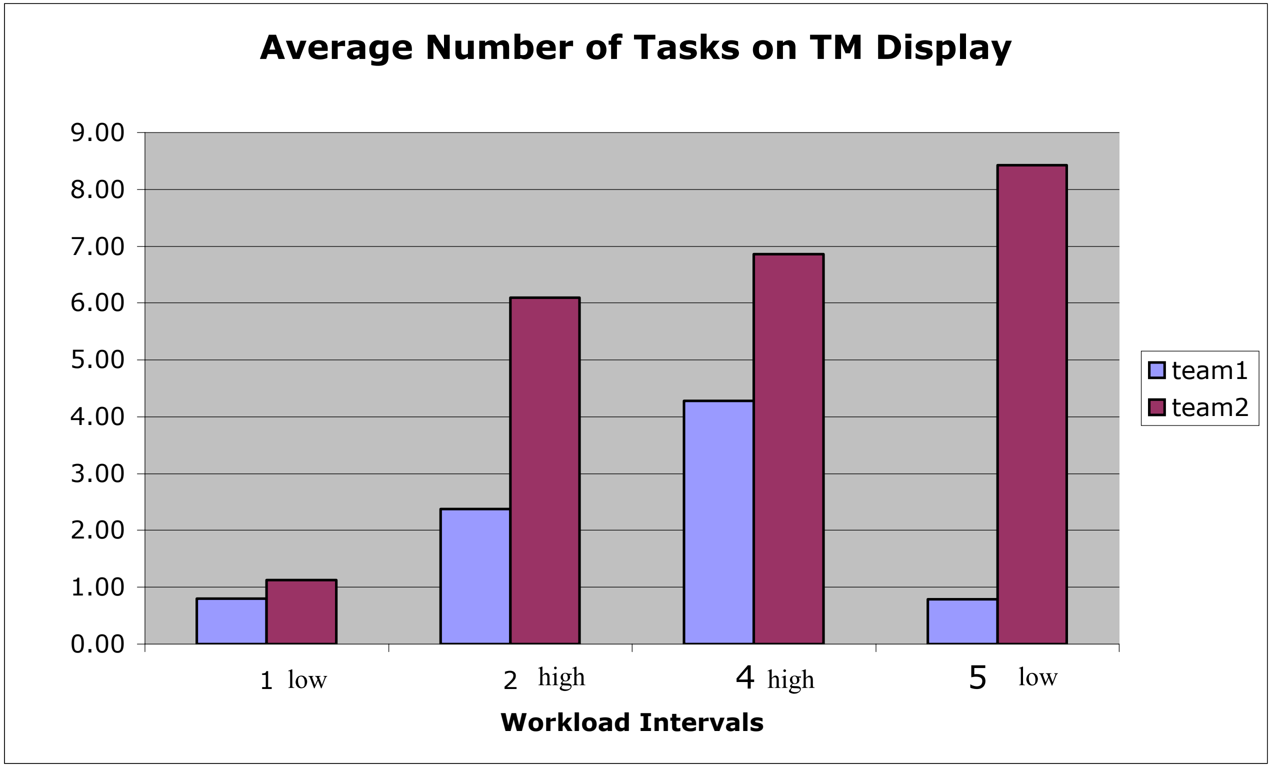
% of Time spent by number of tasks to perform.



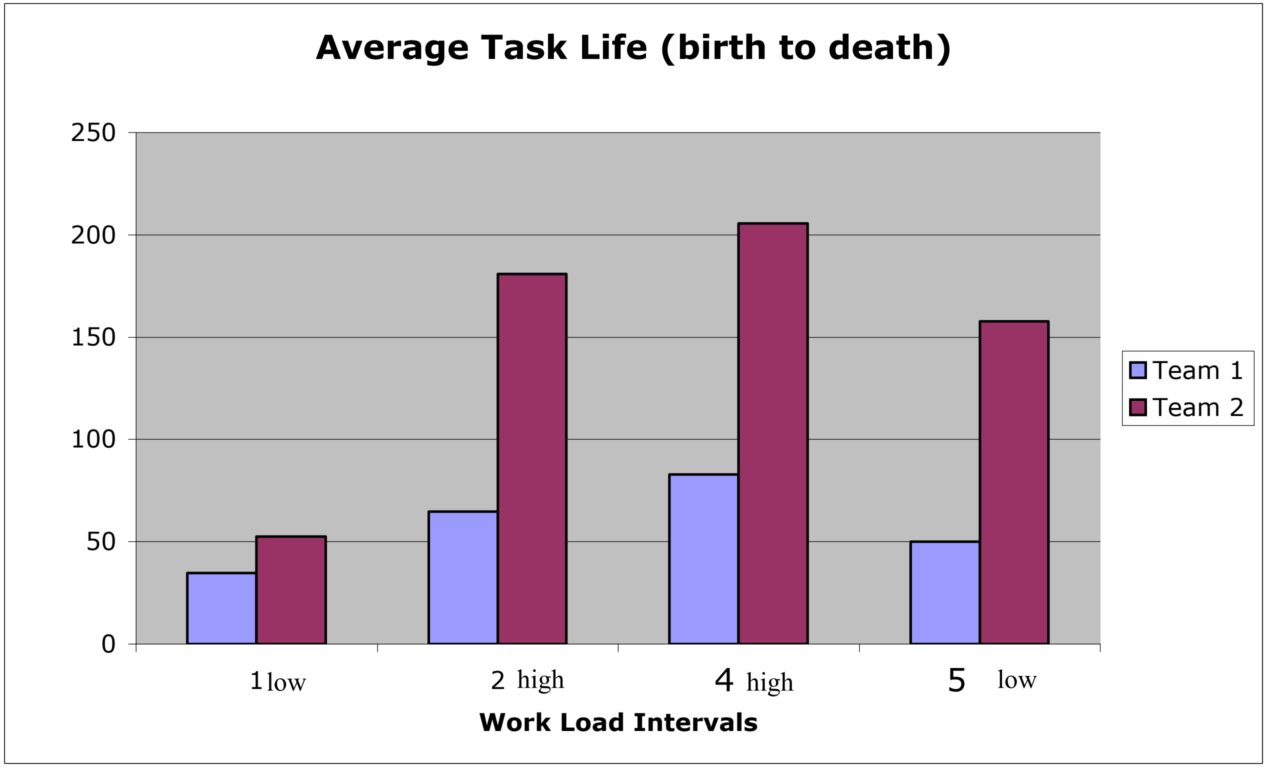
Scenario Interval 1 (Low workload) Scenario Interval 2 (High workload).

Higher workload interval marks a shift in states where AWC begins to fall behind completing tasks.

Team 1 and 2 AWC Average Number of Tasks During Low and High Work Load Intervals



Team 1 and 2 AWC Average Task Life During Low and High Work Load Intervals



Team Task Allocation

- AWC for Team 2 falls behind in his work to a much greater extent than the AWC for Team 1.
- Why? - Analysis of Teams revealed that Task Allocation and Work Flow was different between these two teams.
- Goal: Modeled these difference with :
  - Network Queueing Theory

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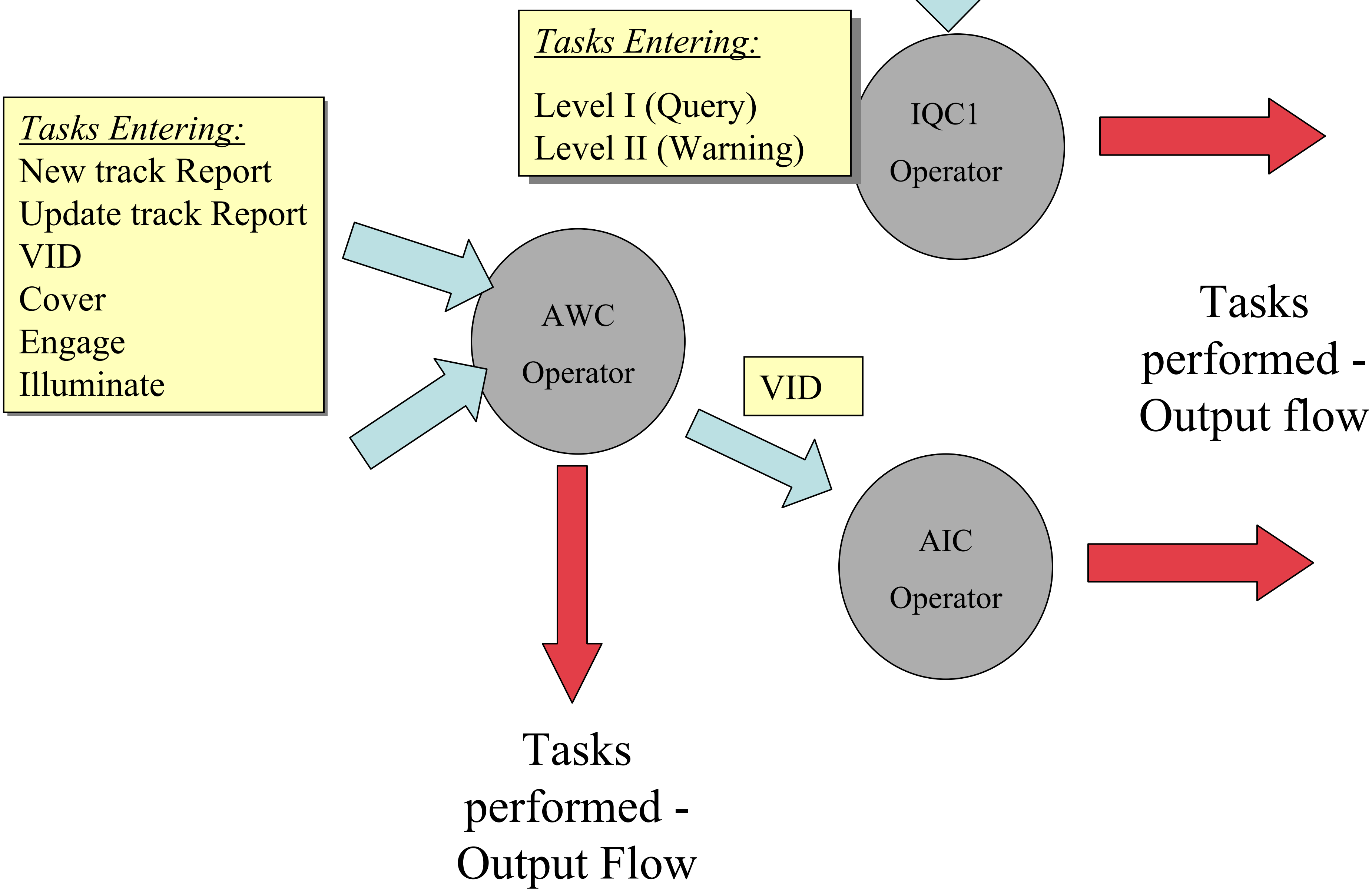
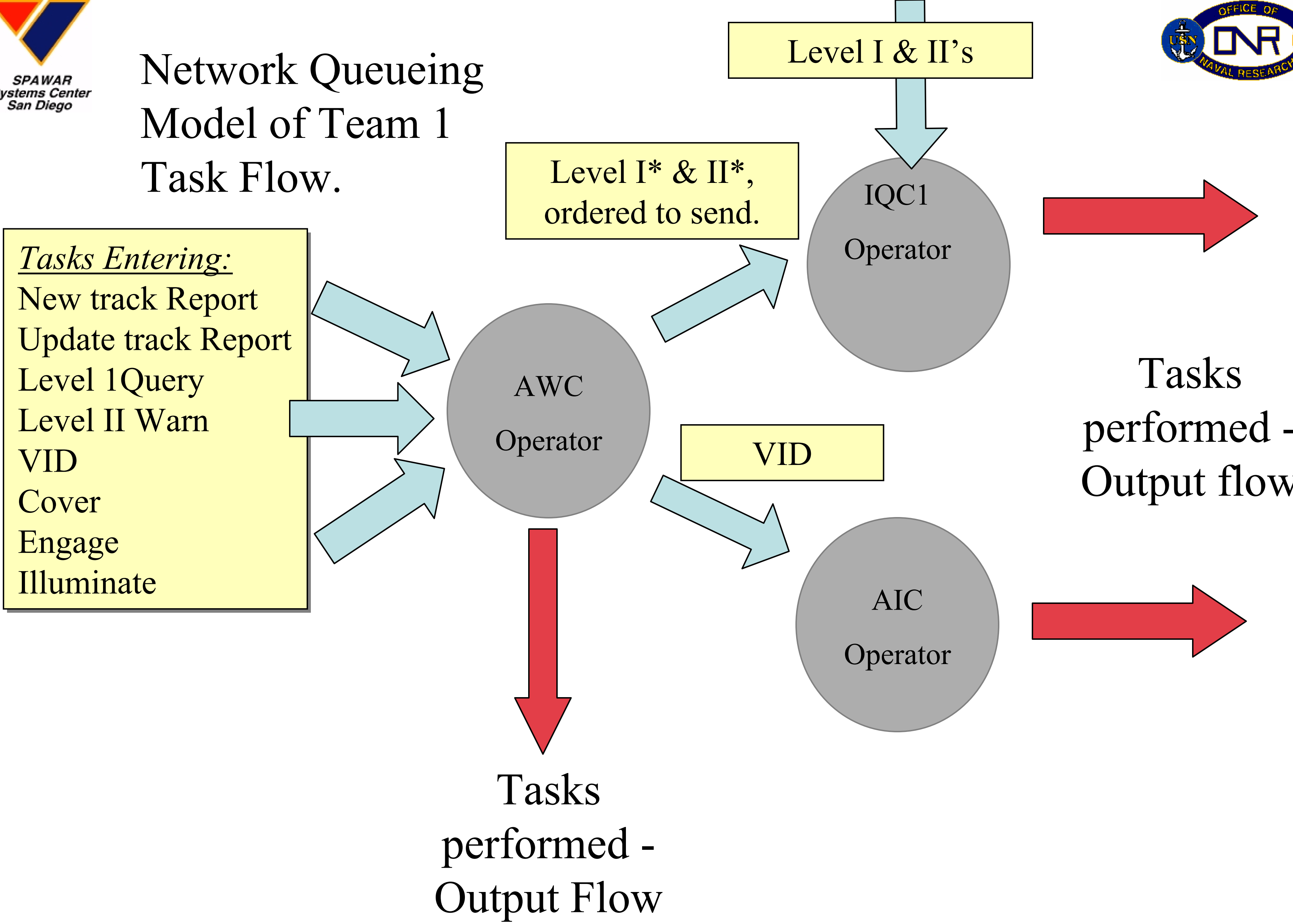
Network Queueing Model of "Ideal Team" - Envisioned by System Developers



Network Queueing Model of Team 1 Task Flow.



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What you are going to see:

9:33 Level 1 track 1035 arrives

9:44 Hear voice of supervisor informing AWC about the Level 1 task.

9:45 AWC selects task

AWC gets side-tracked listening to Bravo Whiskey

New tasks begin to pile up.

10:13 AWC orders IQC1 to send Level 1.

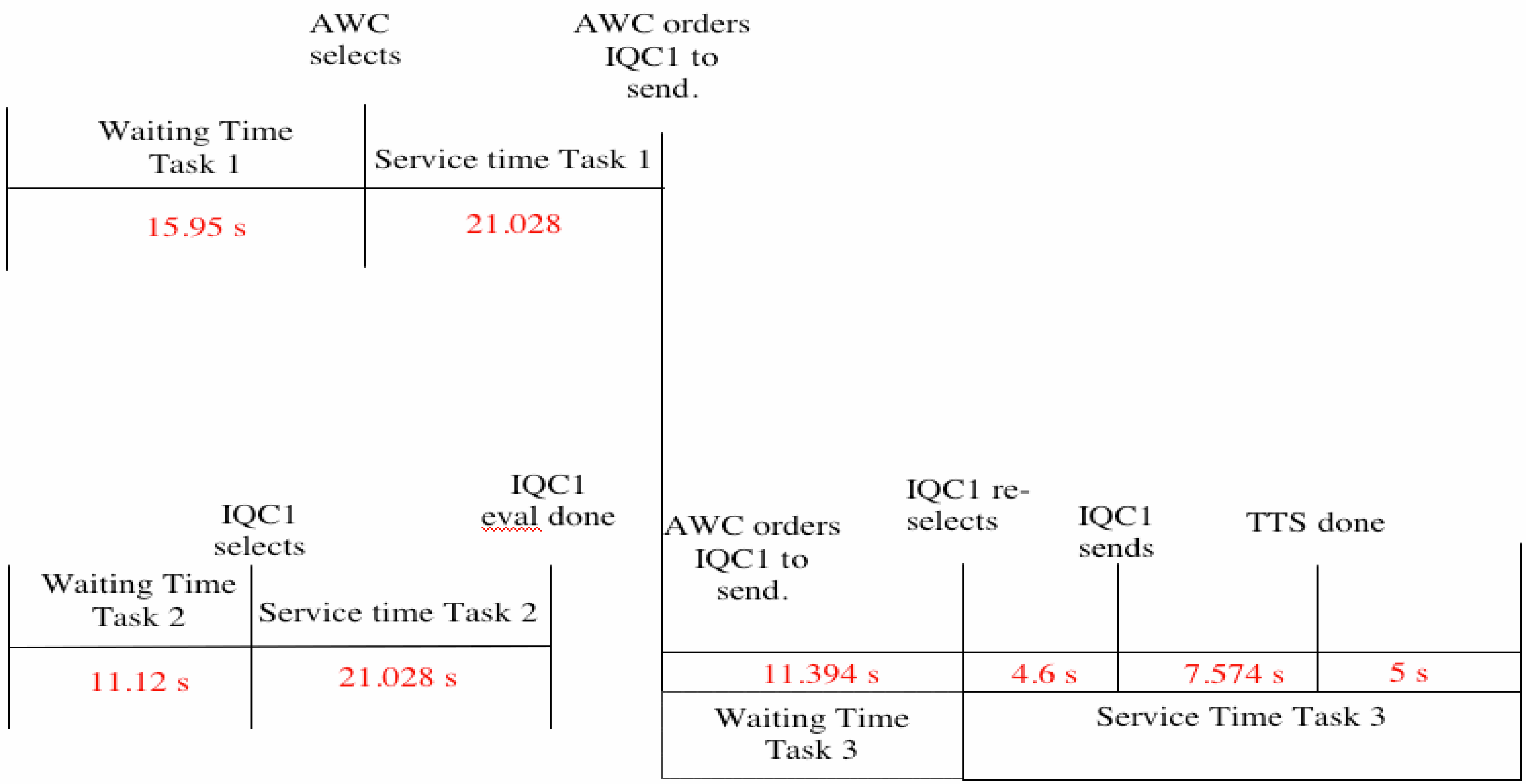
10:18 IQC1 acknowledges order.

What you don't see but we know from data log

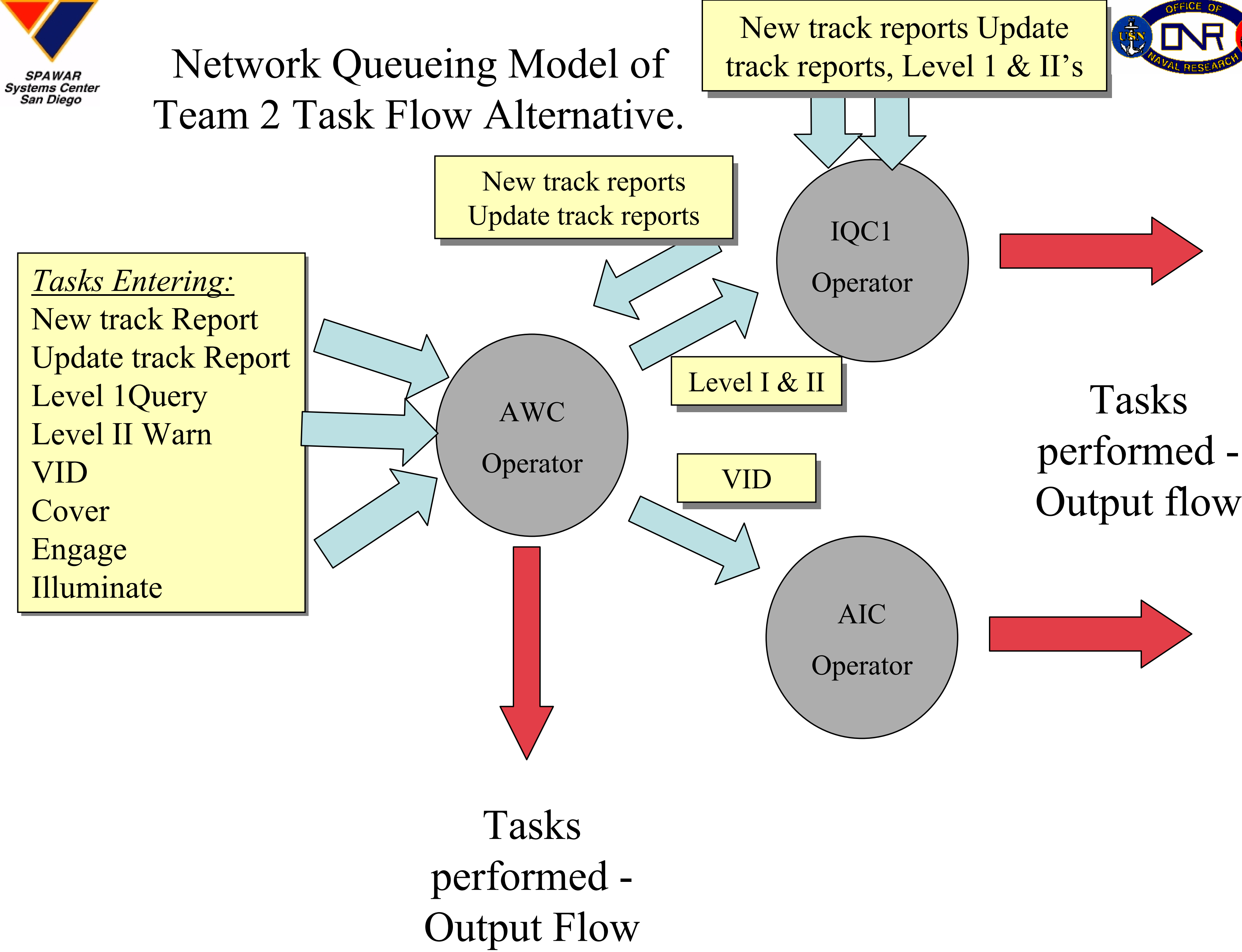
IQC1 selects task *only after* AWC orders him to send.

IQC1 selects task at **10:38** and sends Level 1 at **10:41**.

Flow of a level 1 query task - AWC and IQC1 are both involved in task - AWC makes decision to send



Network Queueing Model of Team 2 Task Flow Alternative.



What you are going to see:

6:00 New Track (NT)1043 (commair) arrives

6:16 New track 1010 (unknown) arrives.

6:16 IQC1 announces NT 1043

6:19 AWC selects 1043 - does not finish task.

6:21 IQC1 announces NT 1010

6:26 AWC selects NT 1010

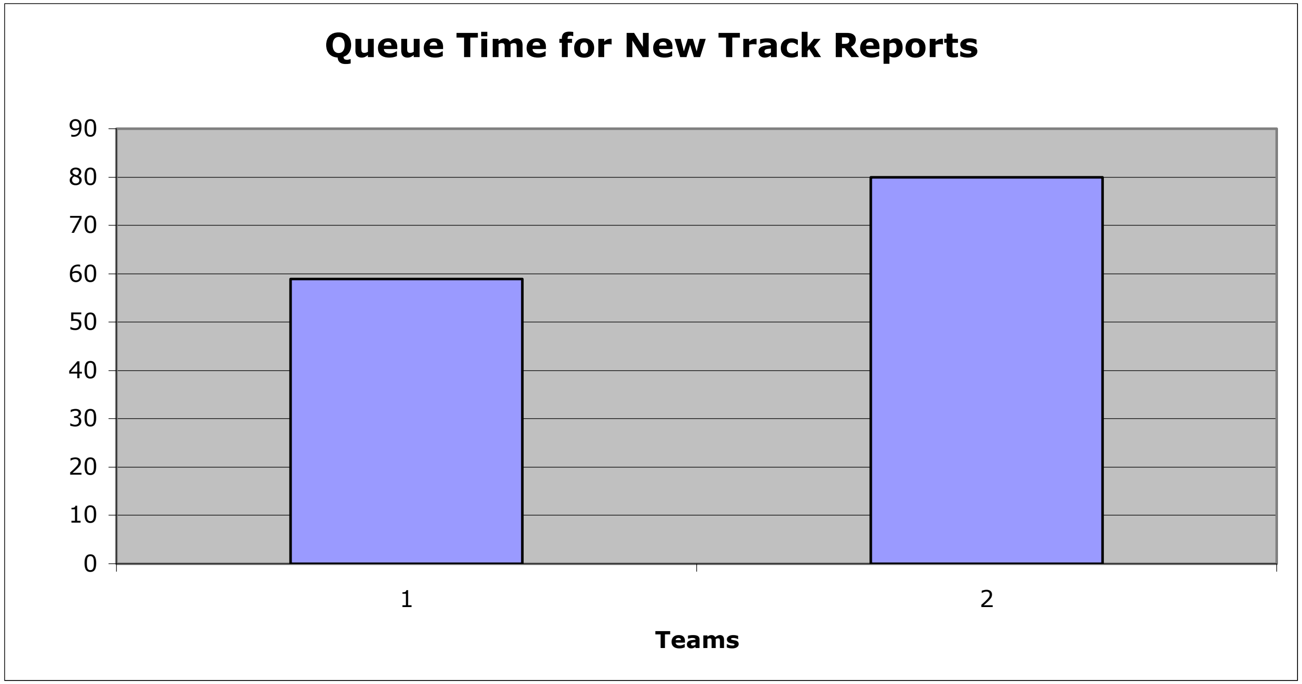
6:37 AWC sends NT report for track 1010

6:40 AWC reselects NT 1043.

6:52 AWC sends NT report for track 1043

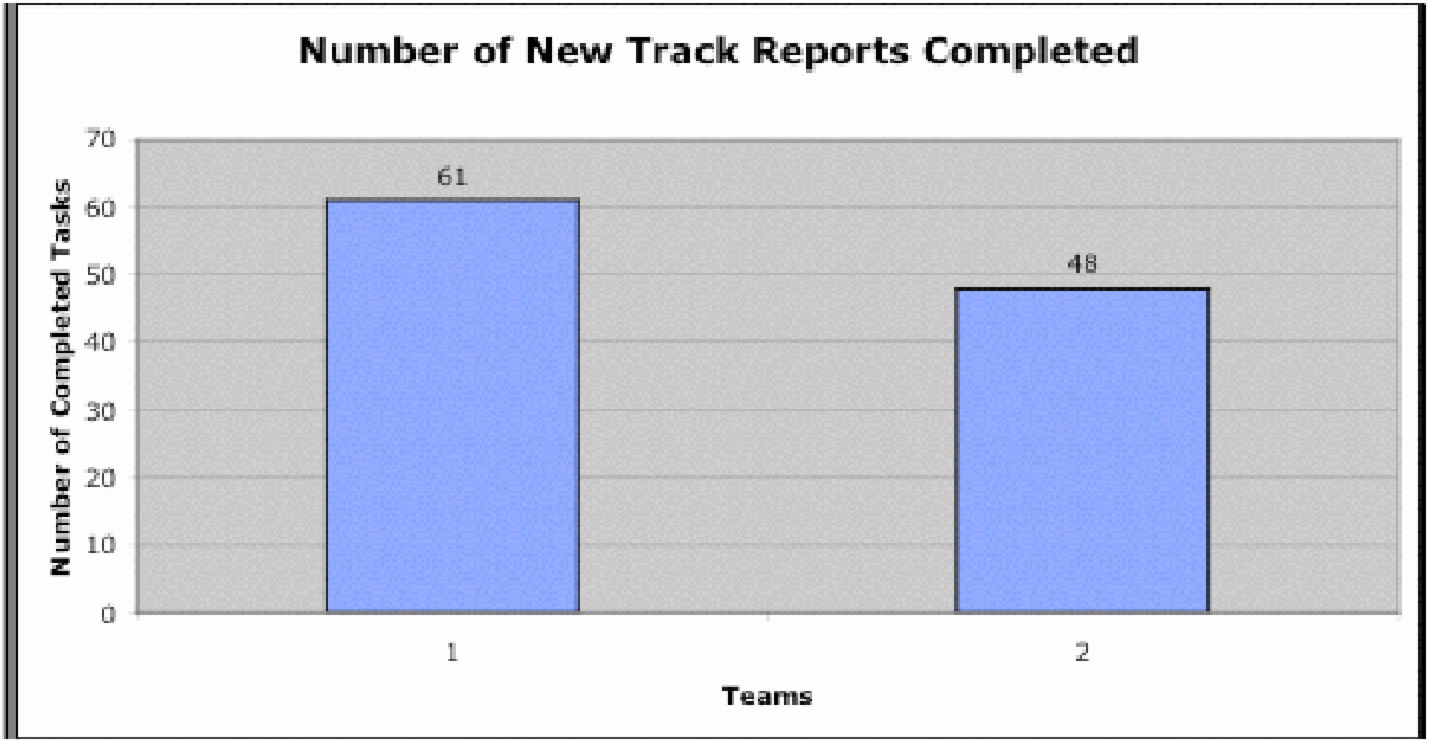
Evidence that Team 2 Handled New Track reports Differently than Team 1

Team 2 takes 36% longer to complete New Track Reports



Evidence that Team 2 Handled New Track reports Differently than Team 1

Team 2 completes 21% fewer New Track Reports than Team 1



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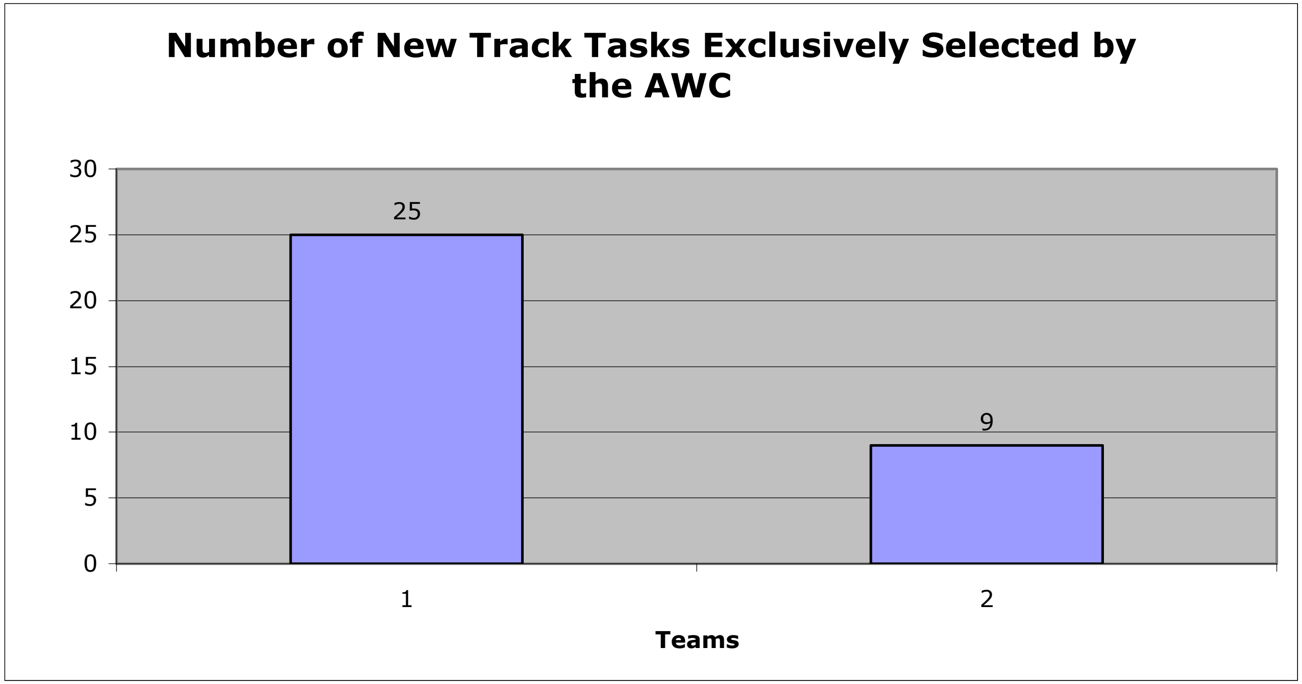
Evidence that Team 2 Handled New Track reports Differently than Team 1

Team 2: More operators are involved with the New Track Report Task for Team 2. AWC rarely is the only operator to select a New Track Report Task.



Conclusions

Performance on New Track Report Tasks was very different for the two teams because:

1) The Teams chose to handle the tasks very differently.
2) Team 2 created sub-tasks that involved more than one operator.
3) Making the task a collaborative effort among team members may have increased Situation Awareness but this came at a price:

   - Increased Queue Time for the New Track Report Task.

General Conclusions

Model-based Design Provides Performance Predictability which is essential to good design.

Current Goals:

1. Develop a predictive model for the Air Defense Warfare team viewed as a queueing network.
2. Evaluate operator, team and system performance with these models.
3. Explore the nature of task allocation and dynamic task reallocation among team members with these models.

General Open Network Queueing Model

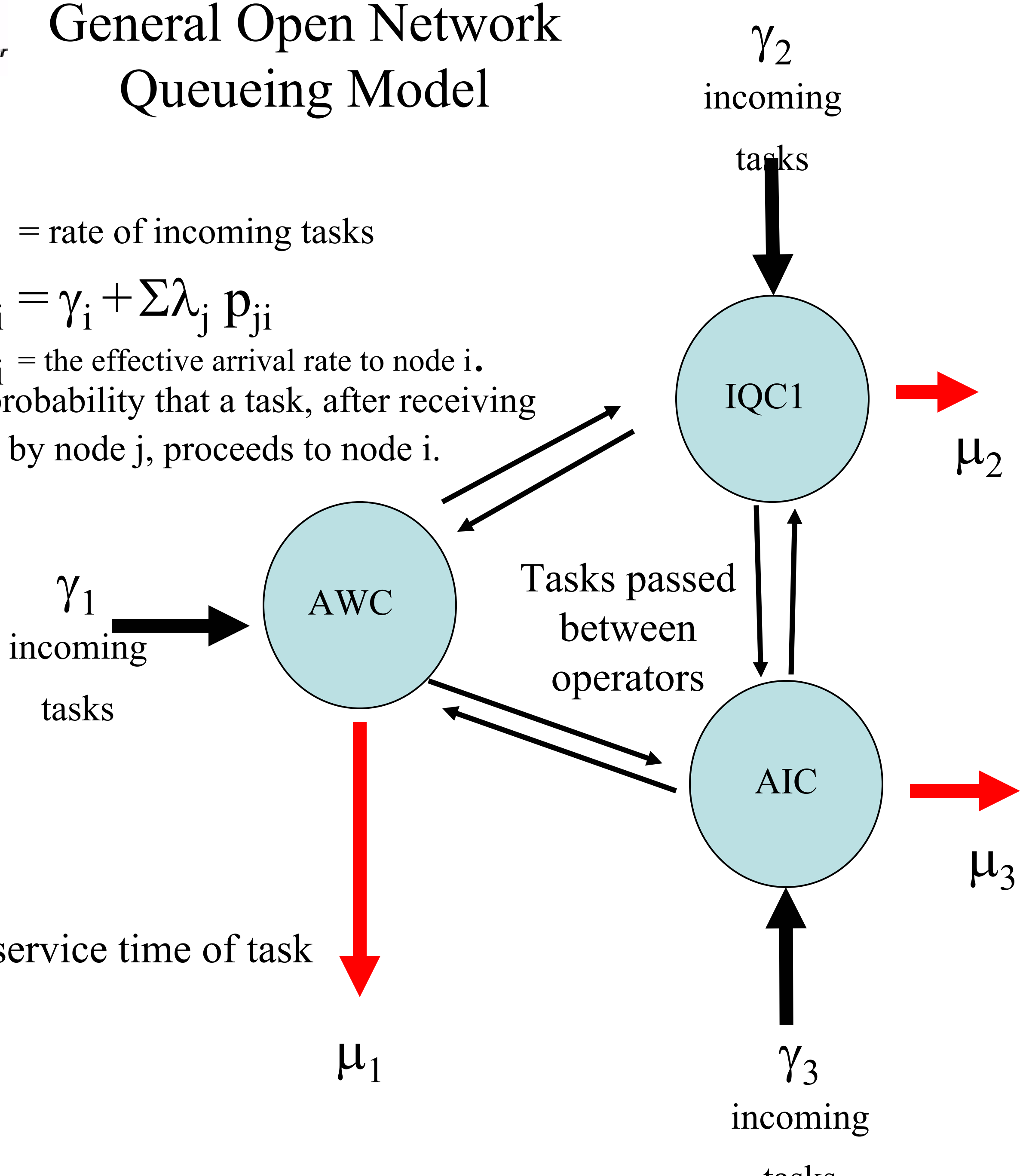
γ_i = rate of incoming tasks

$\lambda_i = \gamma_i + \Sigma \lambda_j \, p_{ji}$

λ_i = the effective arrival rate to node i.

p_{ji} = probability that a task, after receiving service by node j, proceeds to node i.

μ_i= service time of task



Network Stats:

Load to each node:

$$\rho_i = \frac{\lambda_i}{\mu_i}$$

Ave #, N, of tasks in the whole system:

$$N = \Sigma \lambda_i / (\mu_i - \lambda_i)$$

Ave time, T, of tasks in the system:

$$T = \frac{1}{\Sigma \gamma_i} \Sigma \lambda_i / (\mu_i - \lambda_i)$$

Probability of a particular state (n_1, n_2, n_3) tasks:

$$P(\tilde{n}) = \Pi (1 - \rho_i) \, \rho_i^{ni}$$

Queueing Theory

- Because the teams handled the tasks differently, the λ_i, μ_i, and ρ_i are different for the different teams, so formulas for average number of task, average time spent in the system, average time spent waiting should yield different results for the different teams.

- One critical aspect of our operators was not captured by these models. Normally when no tasks are present, the server is idle; however, this was not the case with human operators. When there were no tasks on the TM displays, operators examined the TACSIT display.

- These non -TM tasks must be taken into account in order to quantify system performance because they will have an impact on the queueing statistics.

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Queueing Theory

- A queue with "service vacations" can be adapted to model our situation (Takagi, 1991).
- If there are no customers in the queue that need to be served, the server takes a vacation.
- If the operator has no tasks on the TM display he "takes a vacation" by analyzing information on the TACSIT display. When he is done looking at the TACSIT display he "returns from vacation" to see if there are any tasks on the TM display.
- We assumed operator's 'vacation times' and service times were both exponentially distributed however the parameters v and μ for vacation time and service time, respectively, are not necessarily equal. Arrival was assumed to be Possion.

Queueing Theory Stats for Vacationing Server

- The waiting time for a queue with service vacations v is:

$$W = \frac{\rho}{\mu - \lambda} + \frac{1}{v}$$

- The average time, T, a task spends in the system is:

$$T = \frac{1}{\mu - \lambda} + \frac{1}{v}$$

- The average Number of customers, N, in the queue:

$$N = \frac{\rho}{1 - \rho} + \frac{\lambda}{v}$$

- We have extended this model to include, task prioritization.
- Network formulas may also be derived.